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By

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Psychological Monographs: General and Applied

Pure-Tone Thresholds Following Stimulation by Narrow-Band Filtered Noise[1]

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THE literature regarding auditory fatigue is abundant. Without attempting an exhaustive review of the literature, the studies of Caussé and Chavasse (3), Davis *et al.* (5), Epstein (7), Harris (10, 11, 12). Hirsh and Ward (14), Rawdon-Smith (22), Rawnsley and Harris (23, 24), and Rosenblith (25), Rosenblith, Galambos, and Hirsh (26), and Rosenzweig and Rosenblith (27) show that much effort has been exerted to relate such factors as the frequency, intensity, and duration of exposure of test sounds to poststimulatory auditory thresholds.

Evidence has appeared indicating that auditory poststimulatory effects can be bidirectional, i.e., either an increase or a decrease in auditory sensitivity can follow intense auditory stimulation. Several investigators have reported what has come to be called "sensitization" (1, 2, 4, 5, 8, 12, 13, 14, 15, 16, 21) following stimulation. It is here defined as a lowering of the normal auditory threshold (or conversely, an increase in normal auditory acuity). Some investigators (1, 13, 16) report that sensitization varies with the frequency of the test tone or with the frequency of the exposure tone. Bronstein (1) found that sensitization was less for low frequency tones and increasingly greater for higher frequencies. Hughes (15) noted maximum sensitization at 300-500 cps. He also reported that one of his three extensively trained subjects showed sensitization to a pure tone after a white-noise stimulus.

One theoretical formulation has been offered to explain sensitization. Hughes suggested *post-tetanic-potentiation*[3] as a possible answer. He believes that the continued stimulation of the auditory system by the exposure sound tetanizes the relevant nerve fibers, provided the sound is of sufficient intensity. Eccles (6) found that continued tetanization of nerve fibers increased the poststimulatory nerve potential. Hughes concluded that sensitization was due to an increase in poststimulatory potentials from the stimulated auditory nerve fibers.

If post-tetanic-potentiation is a valid explanation for sensitization, then a broad-band noise source used as an exposure sound at an appropriate intensity should result in sensitization for tones within the frequency limits of the noise-band stimulus. On the other hand, if the noise were fed through the proper acoustic filters and a narrow gap removed from it, there should be less or perhaps no sensitization for frequencies within the filtered gap because less tetanization should result in a decreased sensitization.

[1] This monograph is a portion of a doctoral dissertation done at the University of Kentucky under the direction of Dr. James S. Calvin. The author wishes to acknowledge the invaluable contributions of Dr. Calvin and the rest of the doctoral committee and of Dr. Max S. Schoeffler who assisted in the development of the theoretical analysis of the results of this study.

[2] The opinions or conclusions contained in the present report are those of the author. They are not to be construed as reflecting the views or endorsement of the Department of the Army.

[3] Eccles (6) defines post-tetanic-potentiation (PTP) as the ". . . relatively prolonged increase in response that occurs after a junctional region has been subjected to repetitive orthodromic activation. . . ." In other words, PTP is an observed, persistent increase in neural activity at a synapse following tetanic stimulation.

If a filtered noise is used as an exposure sound and pre- and postexposure thresholds are determined for tones within the filtered gap, reasoning suggests that the receptors associated with the frequency area within the filtered gap would receive less stimulation during exposure and, therefore, be characterized by a different poststimulatory response than for those of frequencies outside the filtered gap. An unfiltered noise stimulus could serve as a control for testing the above hypothesis.

The purpose of the present study was to determine the effect of filtered and unfiltered noise stimuli at two sensation levels upon the poststimulatory thresholds for pure tones located in and outside the filtered gap.

I. Apparatus

The noise stimuli were recorded on high-fidelity magnetic tape using an Ampex 600 series recorder. The recording was made at a tape speed of 15 inches per second. The white-noise source was a Gerbrands Noise Generator, P.A.L., type 422. A gap extending from 100 to 600 cps was filtered from the noise by passing the signal through two series-connected Krohn-Hite 350-A ultra-low-frequency rejection filters which were placed ahead of the recorder. The filters were calibrated by a series of pure-tone input signals from a Hewlett Packard model 200-C audio-oscillator.

A block diagram of the apparatus used is shown in Fig. 1.

II. Subjects and Procedure

Seven subjects (*Ss*) were used. All of the *Ss* but one had had prior experience in attending to auditory stimuli in experimental studies. All *Ss* had normal monaural acuity (best ear). Normal is here defined as acuity of not more than 10 db below normal at the octave frequencies 125-8000 cps. An otological examination was given all prospective *Ss* and none was accepted who showed any evidence of ear, nose, or throat pathology. An alternate loudness balance test was used to screen for recruitment. None of the *Ss* used in this study showed recruitment.

1. KROHN-HITE MODEL 440-A OSCILLATOR
2. AMPEX MODEL 400 TAPE RECORDER
3. R.W. CRAMER INTERVAL TIMER
4. FISHER MODEL 50C PRE-AMPLIFIER
5. FISHER MODEL 50A AMPLIFIER
6. CLICKLESS SWITCH
7. HEWLETT-PACKARD MODEL 350 ATTENUATOR
8. WESTON MODEL 769 VTVM
9. DUMONT TYPE 218 CRO
10. UTC LS34 MATCHING TRANSFORMER
11. PERMOFLUX PDR-10 EARPHONES WITH DOUGHNUT CUSHIONS
12. LANGE OF LEXINGTON, WAXED PAPER RECORDER AND HAND HELD SWITCH

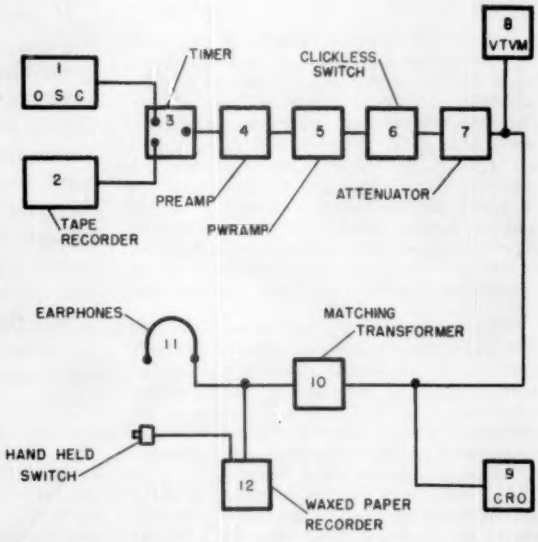

Fig. 1. Block diagram of apparatus.

All testing was done in a sound-treated room with an average ambient noise level of 45 db. *Ss* wore earphones with doughnut cushions which provided about 20 db attenuation of environmental sound. Thus, the *Ss'* thresholds were determined against a 25 db background (45 db ambient noise minus 20 db earphone attenuation).

The serial method of limits was used to determine all thresholds. Each threshold was fixed by 4 crossings, 2 ascending and 2 descending series. The *Ss* were stimulated monaurally and monaural thresholds were taken.

Familiarization training was given to each *S* before the experiment was begun. This training consisted of 3 complete audiograms, 5 trials to determine thresholds for the study, and 2 white-noise threshold determinations.

As soon as the *S* came into the testing room the earphones were placed upon his head and he was seated. His threshold for the test-tone he was to be exposed to for the experimental session was then determined and he was exposed for 4 minutes to the filtered or the unfiltered noise. At the end of the 4-minute exposure period the noise was terminated, the test-tone circuit was switched on, and the experimenter began determining the *S's* postexposure thresholds for the test-tone. The order of presentation of the variables of intensity, test-tone frequency, and filtered or unfiltered noise exposure was randomized.

III. Experimental Variables

Two sensation levels were used, one of 100 db SL, the other of 20 db SL.

The *Ss* were exposed to 2 different exposure sounds, a filtered and an unfiltered noise. The filtered noise had a gap filtered from 100 to 600 cps with a center frequency maximum attenuation of 25 db. The unfiltered noise stimulus was broad-band noise with a fairly flat spectrum. Duration of exposure to the noise stimuli was 4 minutes, with 4 hours intervening between experimental sessions.

The test-tone frequencies were as follows: one tone of 255 cps as the center frequency (which corresponded to the center frequency of the filtered gap), a tone of 350 cps which was above the center frequency, and one of 162 cps which fell below the center frequency.

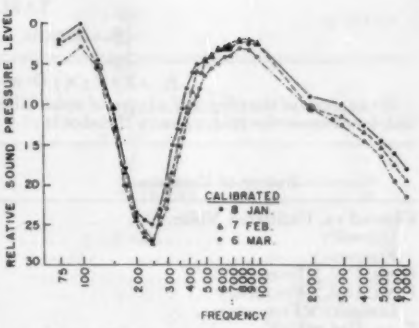

Fig. 2. Calibration of the filtered noise.

The 162- and 350-cps tones in the filtered gap were attenuated approximately half as much as the 255-cps tone. Then signals of 600-cps and 100 cps were selected. These signals were chosen because they fell at the lower and upper edges of the filtered gap. Test-tone frequencies were selected by examining the calibration curve of the filtered noise (see Fig. 2).

Five postexposure thresholds were taken within time intervals of 45 seconds, 90 seconds, 2 minutes, 4 minutes and 8 minutes after termination of the exposure sound.

IV. Results

The major finding of this study is that *Ss stimulated with the unfiltered noise consistently had higher postexposure thresholds for pure tones within the filtered gap* than did those who were stimulated with the filtered noise. This suggests that the unfiltered noise produced auditory fatigue while the filtered noise resulted in sensitization. The above possibility was tested by the paired replicates test (23). Results of the statistical analysis of the data may be seen in Table 1. Figs. 3, 4, and 5 present the graphical analysis of the data.

When unfiltered noise at 100 db SL was presented, poststimulatory sensitivity to all test-tones was lowered (Fig. 4).

TABLE 1

STATISTICAL ANALYSIS OF DATA

A. 2×2×5×7 Over-all Analysis of Variance

An analysis of the effects of 2 types of noise (filtered and unfiltered), 2 intensity levels, and 5 different test-tones upon the postexposure thresholds of 7 *Ss*.

Source of Variance	*df*	Sum of Squares	Mean Square	*F*
Filtered vs. Unfiltered Noise	1	1408.11	1408.11	142.96**
Intensity	1	584.25	584.25	59.31**
Frequency	4	337.85	84.46	8.57**
F. vs. Unf. × Intensity	1	460.84	460.84	46.79**
F. vs. Unf. × Frequency	4	347.18	86.79	10.14**
Intensity × Frequency	4	157.57	39.39	4.60*
F. vs. Unf. × I × F	4	225.05	56.26	8.29**

B. 2×5×7 Analysis of Variance of the 100 db Data

Source of Variance	*df*	Sum of Squares	Mean Square	*F*
Filtered vs. Unfiltered Noise	1	1740.00	1740.00	70.73**
Frequency	4	460.60	115.15	12.92**
F. vs. Unf. × Frequency	4	548.70	137.10	22.77**
Conditions × *Ss*	6	147.70	24.60	4.09*

C. 2×5×7 Analysis of Variance of the 20 db Data

Source of Variance	*df*	Sum of Squares	Mean Square	*F*
Filtered vs. Unfiltered Noise	1	128.94	128.94	18.14**

* Significant beyond the .01 level of confidence.
** Significant beyond the .001 level of confidence.

Stimulation by unfiltered noise at 20 db SL resulted in significant fatigue only for the test-tones of 100 and 600 cps (Fig. 3). Stimulation by the filtered noise at 100 db SL resulted in statistically significant sensitization for the 162- and 255-cps test-tones, while fatigue was found for the 100- and 600-cps tones (Fig. 5). At the 20 db SL, statistically significant sensitization was found for only one test-tone, that of 350 cps. Signal detection was found to be significantly better after filtered noise stimulation than following unfiltered noise exposure.

Generally, the fatigue effect was more prominent and more consistent than the sensitization effect. The fatigue effects for the unfiltered noise were essentially the same for all the test-tones while the sensitization effect following filtered-noise stimulation tended to follow the filtering effect. This may be seen by comparing Figs. 5 and 6.

Results indicate that fatigue and/or sensitization are greater following 100 db SL stimulation, than 20 db SL stimulation (Fig. 5).

The temporal course of postexposure thresholds was shown to vary as a function of whether there was initial poststimulatory fatigue or sensitization. Where poststimulatory fatigue was found, the fatigue tended to decrease with time (See Figs. 3 and 4). An analysis of the data of the individuals showed that where sensitization was observed initially, the next threshold was more sensitized in the records of four out of six *Ss*. In one of the

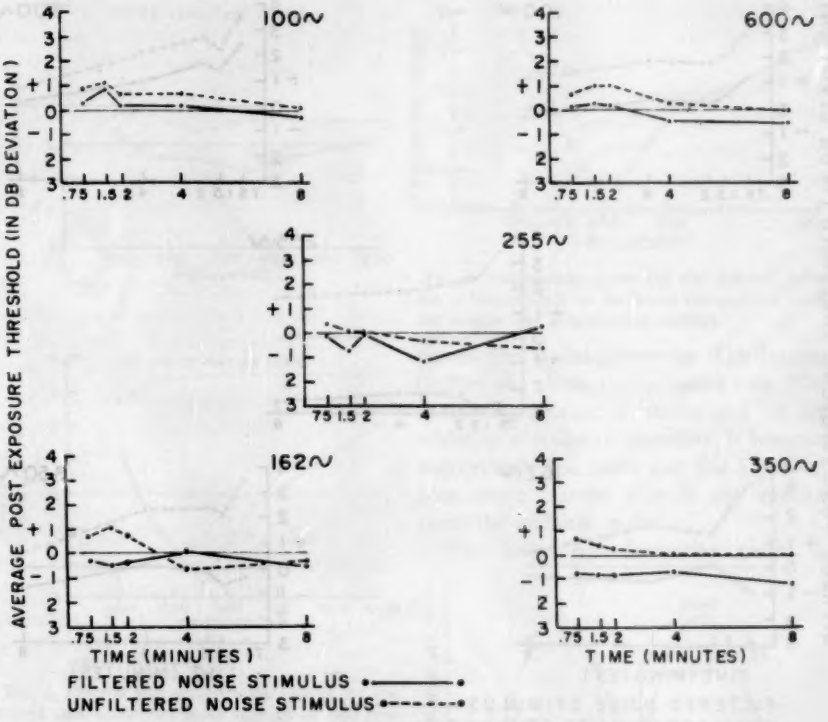

FIG. 3. The pooled data for all *Ss*, showing the temporal course of the postexposure thresholds for the 20 db SL stimulation.

two sensitization cases which did not respond as above, all postexposure thresholds were at essentially the same level. The other sensitization example showed that, after the initial sensitization, sensitivity decreased, increased, then decreased again. The temporal course of the postexposure thresholds is shown by Figs. 3 and 4.

During the course of the experiment four of the seven *Ss* consistently reported tinnitus following 100 db SL stimulation. At the end of the experiment the experimenter asked the *S* to match the pitch of a pure tone from a signal generator to the frequency of his tinnitus. The tinnitus following the unfiltered noise was generally of a higher frequency than that following the filtered noise. In every case, the subjective tinnitus was of a higher pitch than the frequency of the highest test-tone used in the study.

V. Discussion

It was found that thresholds for tones within the filtered gap were lower following filtered-noise stimulation and higher following unfiltered-noise stimulation. Hughes (15) explained sensitization as due to post-tetanic-potentiation. The results of the present study are opposite those that would be predicted on the basis of post-tetanic-potentiation. The post-tetanic-potentiation hypothesis

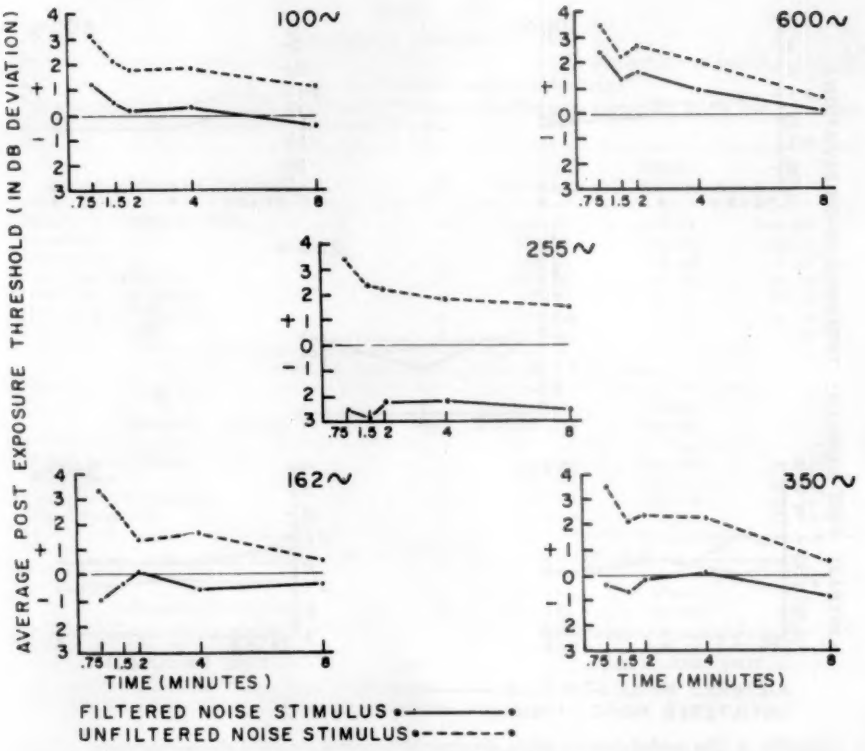

FIG. 4. The pooled data for all Ss, showing the temporal course of the postexposure thresholds for the 100 db SL stimulation.

would predict that more sensitization should result after the unfiltered noise.

The results of this study, though not explained in the literature, might be explained in a formulation borrowing from Tanner and Swets (29) their ideas regarding the hypothetical distribution of noise and signal-plus-noise for intensity, and their philosophy that the problem of detection is one of the detection of signals in noise.

It may be assumed that any sensory channel is continuously activated. The origin of this activity, hereafter referred to as ambient noise, may be ambient stimulation, neural noise, or both.

The ambient noise is assumed to approximate white noise. By definition, at a given frequency the intensities which would result if the noise were continuous would be distributed normally about a mean intensity which is the intensity of the noise. Assume further that the listener can discriminate perfectly (to be qualified later) among signals[4] of different frequencies, and in an experiment

[4] The term *signal* is used to refer to an experimentally produced stimulus while the word *stimulus* is used to mean any stimulation which activates the auditory system of the *S*. The term *stimulus* does, of course, include stimulation by ambient noise.

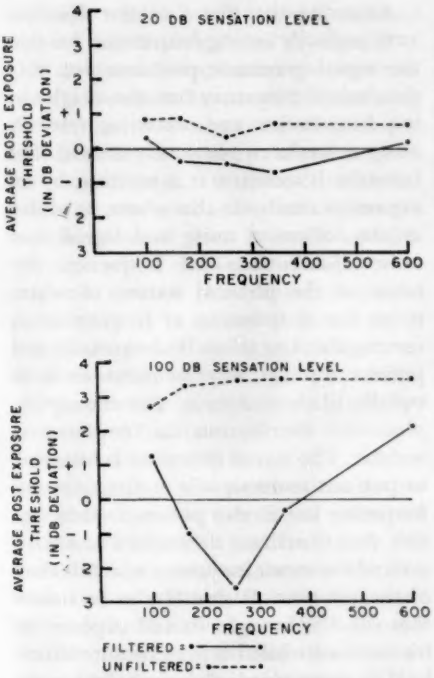

FIG. 5. Fatigue and sensitization curves for the filtered and unfiltered noise stimuli at two sensation levels. (This figure is derived from the pooled data of Figs. 3 and 4.)

is set to detect signals of only one frequency, that of the test-tone.

The hypothetical noise and signal-plus-noise distribution for intensity and frequency may be seen in Fig. 7.

When an *S* is instructed to listen for a signal he attempts to decide whether or not a signal is present. *At all times* a stimulus of the expected frequency is present since it is a component of the ambient noise. Since intensities at a given frequency are normally distributed, when the *S* gets a stimulus of a given intensity, he must decide whether it is likely that the stimulus came from the noise that is always in the system. As the intensity of the stimulus increases it

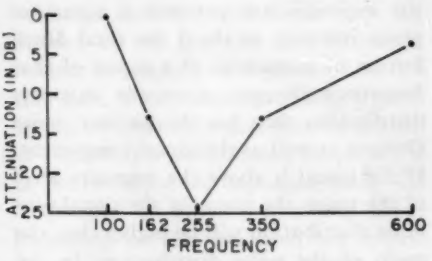

FIG. 6. Calibration curve for the filtered noise (on a linear scale to facilitate comparison with the fatigue and sensitization curves).

moves the signal-plus-noise distribution farther out along the intensity axis. The noise distribution is unchanged by the addition of a signal; therefore, it becomes increasingly less likely that the *S* will say that more intense stimuli are coming from the ambient noise.

The following alternative exists. If

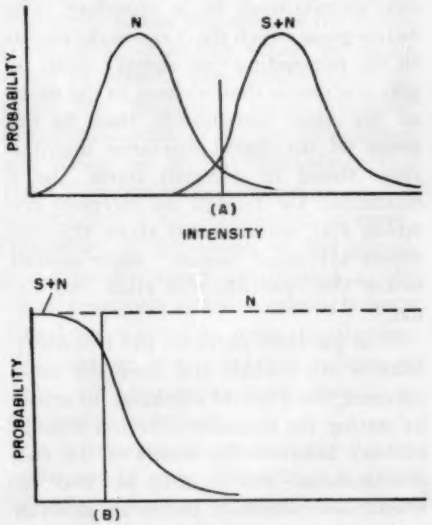

FIG. 7. The distributions of noise (N) and signal-plus-noise (S + N) for intensity and frequency.

the experimenter presents a signal of given intensity to the *S* the total distribution of intensities of a signal of that frequency changes, since the intensity distribution then has the ambient noise element as well as the signal component. If the signal is above the intensity level of the noise, the mean of the signal-plus noise distribution will be higher than the mean of the noise distribution. In the absence of a signal, the *S* samples only the noise distribution. But when a signal is introduced, the *S* samples a signal-plus-noise distribution that differs from the noise distribution. Therefore, higher intensity stimuli are more likely from the signal-plus-noise distribution.

Although the *S* is instructed to respond in some way when he hears a specific signal, his actual task, if this explanation is correct, is to decide which of the two *distributions* he is sampling. The better guess which the *S* can make results in his responding "no signal" when he gets a stimulus that is closer to the mean of the noise distribution than to the mean of the signal-plus-noise distribution. Stated in different terms, the *S* establishes for himself an intensity criterion and any stimulus above this criterion will elicit "signal," while stimuli below this criterion will elicit "no signal."

If, as has been assumed, the two distributions are normal and have the same variance, the *S* would minimize his errors by setting his intensity criterion exactly halfway between the means of the two distributions. But it may be that he would not minimize errors in general, but minimize errors of a particular kind. If this were the case the intensity criterion would be set elsewhere. For example, if it were important to detect all signals but not important if false responses were made, the intensity criterion would be lowered.

Assuming that the *S* cannot discriminate perfectly among frequencies (or that the signal generator produces not only the desired frequency but also neighboring frequencies) and assuming (erroneously as has been previously shown) that intensity is constant, it is possible, by an argument similar to that above, to arrive at the following noise and signal-plus-noise distributions for frequency. Because of the physical nature of white noise, the distribution of frequencies is rectangular, i.e., all audio-frequencies are present and at any moment each is equally likely to appear. But the signal-plus-noise distribution for frequency is not flat. The signal generator is assumed to put out more signals at the test-tone frequency but it also puts out other signals that distribute themselves normally around the mean frequency which is that of the test-tone. It should also be noted that the *S* is brought in and exposed to his test-tone while his pre-exposure threshold is determined; therefore, he knows what signal to expect. But since the *S* cannot discriminate perfectly among frequencies he is more likely to respond "signal" to a tone of the same frequency as the test-tone and increasingly less likely to respond "signal" to tones as they differ in frequency from the test-tone. If this were true, the signal-plus-noise frequency distribution would be symmetrical about the modal point, i.e., the probability of a response to a stimulus would be decreased as the stimulus differs in frequency from the center frequency (which is that of the test-tone), regardless of whether the frequency difference is higher or lower with regard to the test-tone. The *S* sets some limit to the amount which the frequency of the stimulus may differ from that of the test-tone and still be called "signal." This may be called a frequency criterion. Thus, any stimulus within the frequency

criterion will be called "signal" and any outside this limit will be "no signal."

If the intensity and frequency assumptions made above are combined, omitting the erroneous assumptions of intensity and frequency constancy that were made for convenience, a three-dimensional graph of the probability of occurrence of a stimulus of given intensity and frequency can be drawn. Probability of a response can be determined once the probability of a stimulus' occurring is known. Figures 8 and 9 represent three-dimensional graphs of the probability of occurrence of a stimulus of given frequency and intensity.

Examination of Figures 7, 8, and 9 shows that part of the noise distribution is included within the region delimited by the *S*'s intensity and frequency criteria. This occurs since the two distributions (noise and signal-plus-noise) overlap and the *S*'s criterion would normally include some of the noise distribution. Also, not all of the signal-plus-noise distribution is included within the *S*'s criterion. This means that some noise stimuli will be called "signal" (a "false alarm") and some signals will be missed.

An additional assumption necessary in the above formulation is that auditory stimulation fatigues the *S* at the stimulating frequency and to neighboring frequencies in a gradient fashion with the maximum fatigue occurring at the test-tone frequency. Figures 8 and 9 show that stimulation at frequencies other than that of the test-tone would affect the sensitivity of the *S* in such a manner that the part of the signal-plus-noise distribution away from the test-tone would be maximally affected. The altered sensitivity of the *S* would also result in the noise distribution's being changed. The basic belief underlying the present formulation is that the relative volume of the noise and the signal-plus-noise distribution included within the area delimited by the intensity and frequency criteria determines auditory response. To elaborate, if an *S* is stimulated by a given signal, his sensitivity decreases for a band of stimuli. The stimulating frequency is at the center of the depressed band, the frequencies on either side of the center frequency are also depressed but to progressively lesser degree. If, after having been stimulated, the *S* has his threshold determined for a given tone for which his normal threshold is known, the change in sensitivity following stimulation can be observed. The above formulation holds that the stimulation would change the *S*'s sensitivity and therefore change the volume of the signal-plus-noise distribution relative to the noise distribution included within the criteria-passing region. If the postexposure signal were at the center frequency of the stimulated band, sensitivity would be maximally decreased. This would occur because the frequency signal-plus-noise distribution peaks at the signal frequency and drops off sharply thereafter. The noise distribution for frequency, on the other hand, is flat throughout its range. Therefore, a depression of the signal-plus-noise frequency distribution at the signal frequency removes relatively more signal-plus-noise than noise distribution. This change in the relative volume of noise and signal-plus-noise should be manifested as fatigue.

It is believed that essentially the opposite would occur when the *S* is stimulated by signals other than at the test-tone frequency. Stimulation by frequencies other than the test-tone frequency would affect the signal-plus-noise distribution in its less peaked area and would affect the noise distribution as before, in a flat area. Therefore, more noise and less signal-plus-noise volume

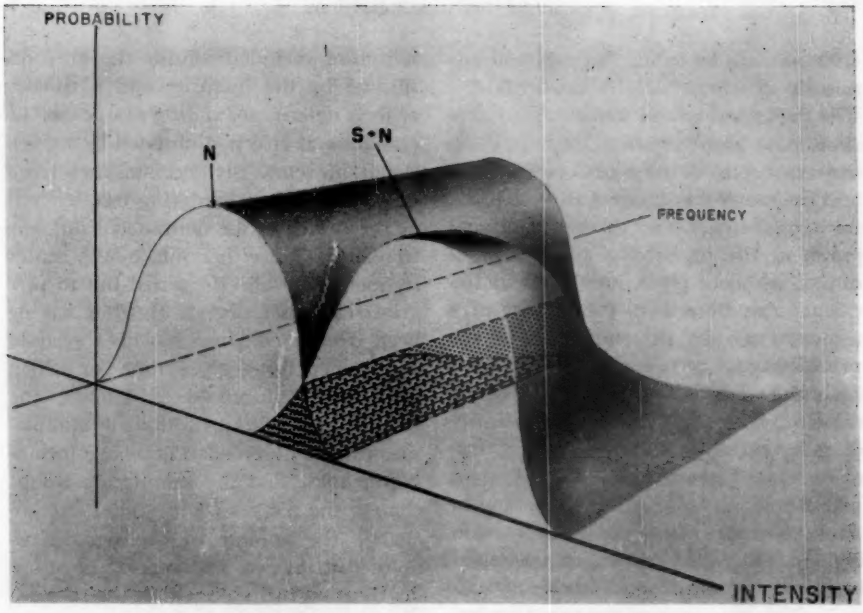

FIG. 8. A three-dimensional graph of the noise (N) and signal-plus-noise (S + N) distributions, showing the overlap between the two distributions.

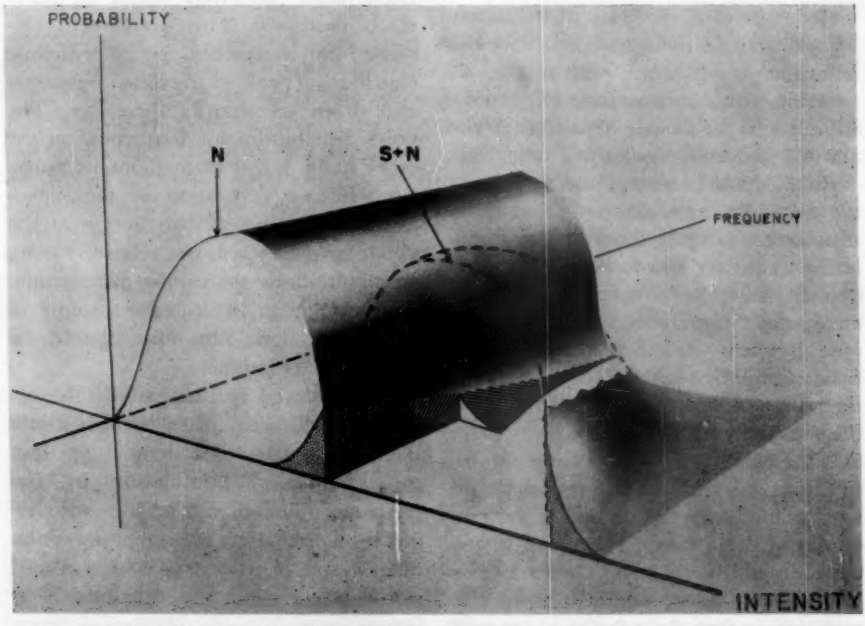

FIG. 9. A three-dimensional graph of the noise (N) and signal-plus-noise (S + N) distributions, showing the area delimited by the intensity and frequency criteria.

would be removed and sensitization would result.

However, the above formulation lacks sufficient generality to account for some of the previously cited sensitization results. Specifically, the above explanation predicts fatigue following stimulation at the test-tone frequency, while the previously cited studies report sensitization. It is apparent that the present formulation must be modified in order to account for these results.

The modification proposed is of the following nature: In this study and in that of Hughes (15) some *S*s reported a postexposure tinnitus. This postexposure tinnitus could be assumed to approximate the frequency of the test tone and to change the shape of the noise distribution for frequency so that it is no longer flat, but peaks at or about the frequency of the tinnitus. If this occurred, whether fatigue or sensitization followed stimulation would be determined by the relative peakedness of the noise and signal-plus-noise frequency distributions. A more peaked noise than signal-plus-noise distribution would result in sensitization (following the previous argument) while if the noise distribution were less peaked, fatigue would ensue.

The significance of the main effects of intensity and frequency have been discussed. Unlike Hughes's study, sensitization following a low level of stimulation was found in the studies reported here.

The Hughes study reported a definite frequency-sensitization function such that test-tones and exposure frequencies below and above the range 300-500 cps produced different results from frequencies within that range. Examination of Figs. 5 and 6 show that in the present study the frequency-sensitization effects were quite similar to the filtering curve. From this it is inferred that differential frequency effects in the range spanned by this study were small or nonexistent. If there had been noticeable differential frequency effects they should have made the frequency-sensitization curve deviate markedly from the filtering curve.

Figure 5 also reveals that fatigue effects for the different frequency test-tones were about equal. These results are consistent with those of Caussé and Chavasse (4), who report that in the frequency range of 100-600 cps spanned by test-tones in this study, little or no fatigue effects can be observed. Several further studies are suggested by the results of this study.

VI. Summary

Pure-tone prestimulation thresholds were found for *S*s who were then exposed for four minutes to the filtered or unfiltered noise stimuli at either a 20 or 100 db sensation level. A series of postexposure thresholds were then determined for the same tone for which the pre-exposure threshold had been found. The pre- and postexposure thresholds were then compared.

The *S*s stimulated with unfiltered noise consistently had higher postexposure thresholds for pure tones within the filtered gap than did *S*s exposed to the filtered noise. Following a 100 db SL stimulation by unfiltered noise, fatigue resulted for all test-tones. Following the 20 db SL only the 100- and 600-cps tones were fatigued. On the other hand, a 100 db SL stimulation by filtered noise produced sensitization for the 162- and 255-cps test-tones and fatigue for only the 100- and 600- cps tones. For the filtered noise at the 20 db SL, sensitization was found only at 350 cps.

Variations in poststimulatory sensitivity following the filtered noise were shown to be correlated with the relative

position of the test-tones with regard to the filtered gap. Results indicate that if fatigue follows 20 db SL stimulation, considerably more fatigue may be expected after 100 db SL stimulation. The same trend appears for sensitization.

The *Ss* were found to detect signals better after filtered-noise stimulation than after unfiltered-noise stimulation.

Within the limitations of this study the temporal course of postexposure thresholds was not found to be of a definite cyclical nature.

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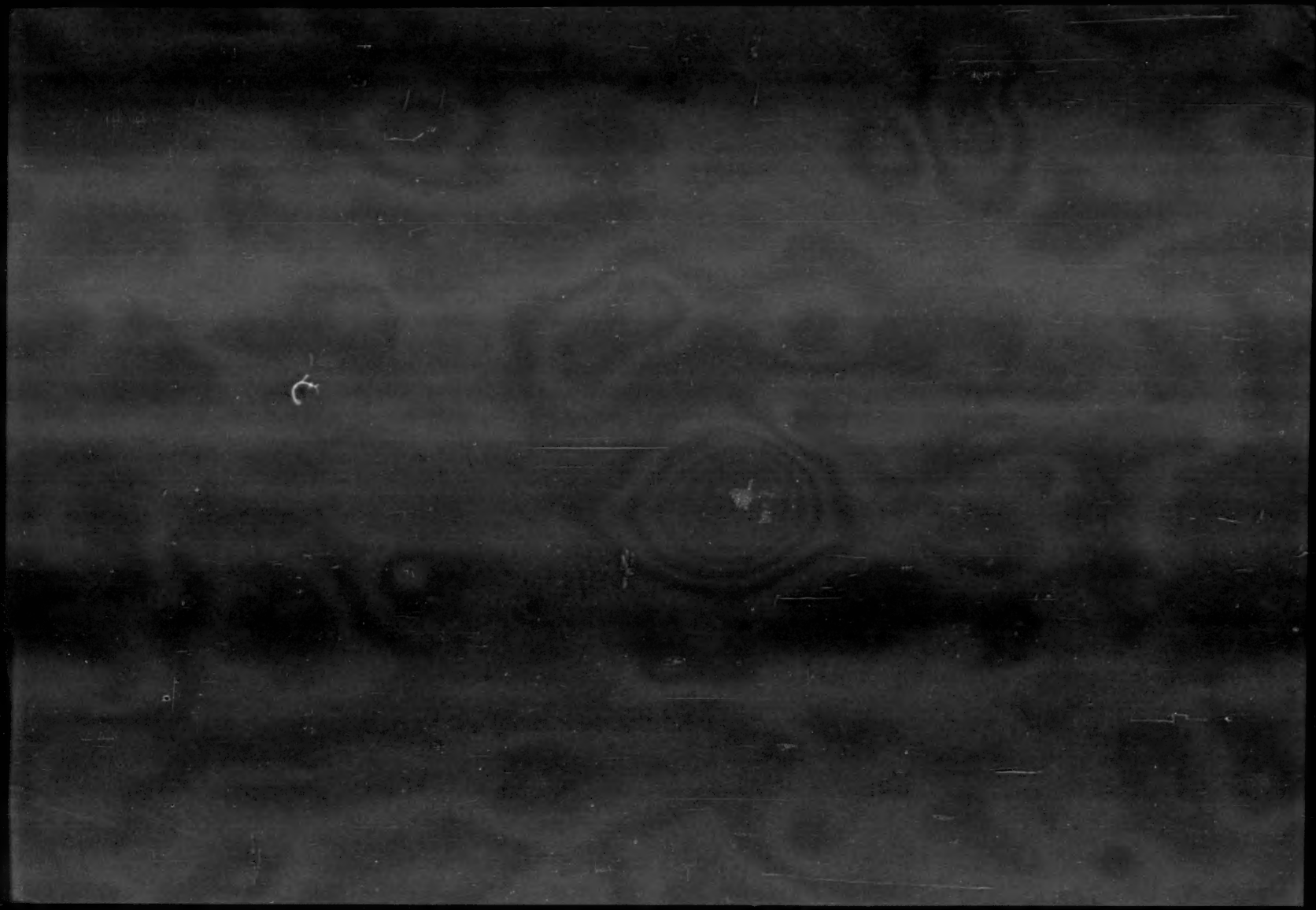
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